

WEAK HYPERNUCLEAR DECAY

Barry R. Holstein

Department of Physics and Astronomy

University of Massachusetts

Amherst, MA 01003

and

Institute for Nuclear Theory

Department of Physics, NK-12

University of Washington

Seattle, WA 98195

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Abstract

Because of Pauli suppression effects the $N\pi$ decay mode of the free Λ is not of importance in hypernuclei with $A \geq 10$. Rather the decay of such hypernuclei proceeds via the nucleon-stimulated mode $\Lambda N \rightarrow NN$, analysis of which presents a considerable theoretical challenge and about which there exists only a limited amount of experimental information. Herein we confront existing data with various theoretical analyses which have been developed.

1 – Introduction to Hypernuclear Decay

The properties of the lambda hyperon are familiar to all of us. Having a mass of 1116 MeV, zero isospin and unit negative strangeness, it decays nearly 100% of the time via the nonleptonic mode $\Lambda \rightarrow N\pi$ and details can

be found in the particle data tables[1]

$$\Gamma_\Lambda = \frac{1}{263\text{ps}} \quad \text{B.R. } \Lambda \rightarrow \begin{cases} p\pi^- & 64.1\% \\ n\pi^0 & 35.7\% \end{cases} \quad (1)$$

The decay can be completely described in terms of an effective Lagrangian with two phenomenological parameters

$$\mathcal{H}_w = g_w \bar{N}(1 + \kappa \gamma_5) \vec{\tau} \cdot \vec{\phi}_\pi \Lambda \quad (2)$$

where $g_w = 2.35 \times 10^{-7}$, $\kappa = -6.7$ and Λ is defined to occupy the lower entry of a two component column spinor. The kinematics are such that for decay at rest the final state nucleon emerges with energy about 5 MeV, which means that the corresponding momentum is $p_N = \sqrt{2M_N E_N} \approx 100$ MeV.

Now, however, consider what happens if the Lambda is bound in a hyper-nucleus. [2] In this case, even neglecting binding energy effects, the 100 MeV momentum of the outgoing nucleon is generally much less than the Fermi momentum of the nucleus so that the decay will be Pauli blocked. A very simple estimate of this effect can be generated within a simple Fermi gas model, wherein, neglecting any effects of binding energy or of wavefunction distortion, one finds

$$\frac{1}{\Gamma_\Lambda} \Gamma_\pi = 1 - \frac{1}{2} \sum_{nj\ell} N_{nj\ell} \langle nj\ell | j_\ell(k_\pi r) | 1S_{\frac{1}{2}} \rangle \quad (3)$$

with $N_{nj\ell}$ being the occupation number for the indicated state. The result of this calculation reveals that the importance of such pionic decays rapidly falls as a function of nuclear mass—

$$\frac{1}{\Gamma_\Lambda} \Gamma_\pi \sim \begin{cases} A = 10 & A = 25 & \dots \\ 1/20 & 1/120 & \dots \end{cases} \quad (4)$$

However, while the existence of the nuclear medium suppresses the $N\pi$ mode, it also opens up a completely new possibility, that of the nucleon-stimulated decay— $\Lambda N \rightarrow NN$. Assuming that the energy is shared equally between the outgoing pair of nucleons one has then $E_N \simeq \frac{1}{2}(m_\Lambda - m_N) \approx 90\text{MeV}$. The corresponding momentum is $p_N \sim 400\text{MeV}$ and is well above the Fermi momentum, so that Pauli suppression is not relevant. According to the above arguments the importance of this nonmesonic (NM) mode compared

Figure 1: Calculated ratio of pionic hypernuclear decay to free lambda decay rate.

to its mesonic counterpart should rapidly increase with A , and this expectation is fully borne out experimentally, as shown in Figure 1. A theory of hypernuclear weak decay then has basically nothing to do with the pionic mode favored by a free Λ and must deal with the much more complex $\Lambda N \rightarrow NN$ process.[3] The observables which can be measured experimentally and should be predicted by theoretical analysis include

- i) the overall decay rate Γ_{NM} ;
- ii) the ratio of proton-stimulated ($\Lambda p \rightarrow np$) to neutron-stimulated ($\Lambda n \rightarrow nn$) decay— $\Gamma_{NM}^p/\Gamma_{NM}^n \equiv \Gamma_{NM}(p/n)$;
- iii) the ratio of parity-violating to parity-conserving decay—

$$\Gamma_{NM}^{PV}/\Gamma_{NM}^{PC} \equiv \Gamma_{NM}(PV/PC)$$

—which is measured, *e.g.*, via the proton asymmetry in polarized hypernuclear decay

- iv) final state n,p decay spectra;
- v) *etc.*

The present experimental situation is somewhat limited. Most of the early experiments in the field employed bubble chamber or emulsion techniques. It was therefore relatively straightforward to determine the ratio of the decay rates of the two modes, but much more difficult to measure the absolute rates. This changed when an early Berkeley measurement on $^{16}_\Lambda\text{O}$ yielded the value[4]

$$\frac{\Gamma_{\Lambda}^{(^{16}\text{O})}}{\Gamma_{\Lambda}} = 3 \pm 1 \tag{5}$$

However, this was still a very low statistics experiment with sizable background contamination. Recently a CMU-BNL-UNM-Houston-Texas-Vassar collaboration undertook a series of direct timing—fast counting—hypernuclear lifetime measurements yielding the results summarized in table 1.[5] In addition, there exist a number of older emulsion measurements in light ($A \leq 5$) hypernuclei, details of which can be found in a recent review article.[6] However, the only experimental numbers for heavy systems are obtained from

	${}^5_{\Lambda}\text{He}$	${}^{11}_{\Lambda}\text{B}$	${}^{12}_{\Lambda}\text{C}$
$\frac{1}{\Gamma_{\Lambda}}\Gamma_{NM}$	0.41 ± 0.14	$1.25 \pm 0.16^*$	1.14 ± 0.20
$\Gamma_{NM}(p/n)$	1.07 ± 0.58	$0.96^{+0.8}_{-0.4}$	$0.75^{+1.5}_{-0.35}$

Table 1: Experimental BNL data for nonmesonic hyperon decay. *Note that we have scaled the experimental number to account to exclude the pionic decay component.

delayed fission measurements on hypernuclei produced in \bar{p} -nucleus collisions and are of limited statistical precision[7]

$$\Gamma({}_{\Lambda}^{238}\text{U}) = (1.0^{+1.0}_{-0.5}) \times 10^{-10}\text{sec.} \quad \Gamma({}_{\Lambda}^{209}\text{Bi}) = (2.5^{+2.5}_{-1.0}) \times 10^{-10}\text{sec.} \quad (6)$$

The problem of dealing with a weak two-body interaction within the nucleus has been faced previously in the context of nuclear parity violation, and one can build on what has been learned therein.[8] Specifically, the weak interaction at the quark level is shortranged, involving W,Z-exchange. However, because of the hard core repulsion the effective NN effects are modelled in terms of long-range one-meson exchange interaction, just as in the case of the conventional strong nucleon-nucleon interaction,[9] but now with one vertex being weak and parity-violating while the second is strong and parity-conserving. The exchanged mesons are the lightest ones— π^{\pm} , ρ , ω —associated with the longest range. (Exchange of neutral spinless mesons is forbidden by Barton’s theorem.[10])

A similar picture of hypernuclear decay can then be constructed, but with important differences. While the basic meson-exchange diagrams appear as before, the weak vertices must now include both parity-conserving *and* parity-violating components, and the list of exchanged mesons must be expanded to include both neutral spinless objects (π^0 , η^0) as well as strange mesons (K , K^*), as first pointed out by Adams.[11] Thus the problem is considerably more challenging than the corresponding and already difficult issue of nuclear parity violation.

One of the significant problems in such a calculation involves the evaluation of the various weak amplitudes. Indeed, the only weak couplings which

Figure 2: Meson exchange picture of nuclear parity violation.

are completely model-independent are those involving pion emission, which are given in Eqn. 2. In view of this, a number of calculations have included *only* this longest range component. Even in this simplified case, however, there is considerable model-dependence, as the results are strongly sensitive to the short-ranged correlation function assumed for the nucleon-nucleon interaction, as will be seen. Below we shall review previous theoretical work in this area and detail our own program, which involves a systematic quark model- (symmetry-) based evaluation of weak mesonic couplings to be used in hypernuclear decay calculations.

2 – Hypernuclear Decay in Nuclear Matter

As discussed above one of the significant problems in the calculation of hypernuclear decay involves the evaluation of the various weak NNM vertices. Indeed, the only weak couplings which are completely model-independent are those involving pion emission, which are given in Eqn. 2. In view of this, a number of calculations have included *only* this longest range component. Even here there is considerable model-dependence, however, as the results are strongly sensitive to the short-ranged correlation function assumed for the nucleon-nucleon interaction. As a warm-up to a realistic calculation then we can begin with a pion-exchange-only calculation in “nuclear matter” (*i.e* a

Transition	Operator
$^1S_0 \rightarrow ^1S_0(I=1)$	$\frac{1}{4}a(q^2)(1 - \vec{\sigma}_\Lambda \cdot \vec{\sigma}_N)$
$^1S_0 \rightarrow ^3P_0(I=1)$	$\frac{1}{8}b(q^2)(\vec{\sigma}_\Lambda - \vec{\sigma}_N) \cdot \hat{q}(1 - \vec{\sigma}_\Lambda \cdot \vec{\sigma}_N)$
$^3S_1 \rightarrow ^3S_1(I=0)$	$\frac{1}{4}c(q^2)(3 + \vec{\sigma} \cdot \vec{\sigma}_N)$
$^3S_1 \rightarrow ^3D_1(I=0)$	$\frac{3}{2\sqrt{2}}d(q^2)(\vec{\sigma}_\Lambda \cdot \hat{q}\vec{\sigma}_N \cdot \hat{q} - \frac{1}{3}\vec{\sigma}_\Lambda \cdot \vec{\sigma}_N)$
$^3S_1 \rightarrow ^1P_1(I=0)$	$\frac{\sqrt{3}}{8}e(q^2)(\vec{\sigma}_\Lambda - \vec{\sigma}_N) \cdot \hat{q}(3 + \vec{\sigma}_\Lambda \cdot \vec{\sigma}_N)$
$^3S_1 \rightarrow ^3P_1(I=1)$	$\frac{\sqrt{6}}{4}f(q^2)(\vec{\sigma}_\Lambda + \vec{\sigma}_N) \cdot \hat{q}$

Table 2: Transition operators of allowed $\Lambda N \rightarrow NN$ transitions from relative S-states. Here \vec{q} specifies the relative momentum of the outgoing nucleons while $\vec{\sigma}_\Lambda, \vec{\sigma}_N$ operate on the $\Lambda N, NN$ vertices respectively.

simple Fermi gas model with $N_n = N_p$ and $P_f \sim 270$ MeV) with and without nucleon-nucleon correlation effects. Here the $\Lambda - N$ relative momentum is very soft so that only 1S_0 and 3S_1 initial states are assumed to be involved. Then

$$\begin{aligned} \Gamma_{NM} &= \frac{1}{(2\pi)^5} \int d^3k_1 \int d^3k_2 \int_0^{k_F} d^3k_i \delta^4(p_i - p_f) \\ &\times \frac{1}{2} \sum_{\text{spin}} |\langle f | \mathcal{H}_w | i \rangle|^2 = \sum_{\alpha\beta} \Gamma_{NM}(\beta \leftarrow \alpha) \end{aligned} \quad (7)$$

We can break this down further by identifying effective transition operators for the various partial wave channels which contribute to the decay process —*cf.* Table 2—in terms of which we find for the total nonmesonic hypernuclear decay rate

$$\Gamma_{NM} = \frac{3}{8\pi\mu_{\Lambda N}^3} \int_0^{\mu_{\Lambda N}k_F} p^2 dp q m_N \left(|a|^2 + |b|^2 + |c|^2 + |d|^2 + |e|^2 + 3|f|^2 \right) \quad (8)$$

where $\mu_{\Lambda N} = \frac{m_\Lambda}{m_\Lambda + m_N}$ arises from the switch from the nuclear rest frame to the ΛN center of mass frame and p, q are related by

$$q^2 = m_N(m_\Lambda - m_N) + \frac{p^2}{2\mu_{\Lambda N}} \quad (9)$$

The results obtained by various groups are displayed in Table 3.

	Adams[11]	McK-Gib[12]	Oset-Sal[13]	UMass[14]
$\frac{1}{\Gamma_\Lambda}\Gamma_{NM}(\text{no corr.})$	0.51	4.13	4.3	3.84
$\frac{1}{\Gamma_\Lambda}\Gamma_{NM}(\text{corr.})$	0.06	2.31	2.1	1.82

Table 3: Non-mesonic hypernuclear decay rates calculated by various groups using pion-exchange only in “nuclear matter.”

	Adams[11]	McK-Gib[12]	Oset-Sal[13]	UMass[14]
$\Gamma_{NM}(p/n)$ (no corr.)	19.4	-	-	11.2
$\Gamma_{NM}(p/n)$ (corr.)	2.8	-	-	16.6

Table 4: Proton to neutron stimulated decay ratios for pion-only exchange in “nuclear matter.”

Obviously there is basic agreement except for the pioneering calculation of Adams.[11] The problems with his calculation were two—Adams used an incorrect value of the weak coupling constant g_w as well as too-strong a tensor correlation, both of which tended to reduce the calculated rate. When these are corrected the corresponding numbers are found to be 3.5 (no correlations) and 1.7 (with correlations) and are in basic agreement with other predictions. From this initial calculation then we learn that the basic nonmesonic decay rate is indeed anticipated to be of the same order as that for the free Λ and the important role played by correlations.

A second quantity of interest which emerges from such a calculation is the p/n stimulated decay ratio, given by

$$\Gamma_{NM}(p/n) = \frac{\int_0^{\mu_{\Lambda N} k_F} p^2 dp q (|a|^2 + |b|^2 + 3|c|^2 + 3|d|^2 + 3|e|^2 + 3|f|^2)}{\int_0^{\mu_{\Lambda} k_F} p^2 dp q (2|a|^2 + 2|b|^2 + 6|f|^2)} \quad (10)$$

and which has been calculated by two of the groups, yielding the results shown in Table 4. An interesting feature here is that the numbers come out so large—proton stimulated decay is predicted to predominate over its neutron stimulated counterpart by nearly an order of magnitude. The reason for this is easy to see. In a pion-exchange-only scenario the effective weak

interaction is of the form

$$\mathcal{H}_w \sim g \bar{N} \vec{\tau} N \cdot \bar{N} \vec{\tau} \Lambda \quad (11)$$

Then $\Lambda n \rightarrow nn \sim g$ but $\Lambda p \rightarrow np \sim (-1 - (\sqrt{2})^2)g = -3g$ since both charged and neutral pion exchange are involved. In this naive picture then we have $\Gamma_{NM}(p/n) \sim 9$, in rough agreement with the numbers given in Table 4.

Armed now with theoretical expectations, we can ask what does experiment say? The only reasonably precise results obtained for nuclei with $A > 4$ are those measured at BNL on ${}^5_\Lambda\text{He}$, ${}^{12}_\Lambda\text{C}$ and ${}^{11}_\Lambda\text{B}$, which are summarized in Table 1. We observe that the measured nonmesonic decay rate is about a factor of two lower than that predicted in Table 3 while the p/n stimulation ratio differs by at least an order of magnitude from that given in Table 4. The problem may be, of course, associated with the difference between the nuclear matter within which the calculations were performed and the finite nuclear systems which were examined experimentally. Or it could be due to the omission of the many shorter range exchanged mesons in the theoretical estimate. (Or *both*!)

Before undertaking the difficult problem of finite nuclear calculations, it is useful to first examine the inclusion of additional exchanged mesons in our calculations. As mentioned above, a primary difficulty in this approach is that none of the required weak couplings can be measured experimentally. Thus the use of some sort of model is required, and the significance of any theoretical predictions will be no better than the validity of the model. One early attempt by McKellar and Gibson, for example, included only the rho and evaluated the rho couplings using both SU(6) symmetry methods as well as the well known but flawed factorization approach.[12] Well aware of the limitations of this method, they allowed an arbitrary phase between the rho and pi amplitudes and they renormalized the factorization calculation by a factor of $1/\sin\theta_c \cos\theta_c$ in order to account for the $\Delta I = \frac{1}{2}$ enhancement. Obviously this is only a rough estimate then and this is only for the rho meson exchange contribution! A similar approach was attempted by Nardulli, who calculated the parity conserving rho amplitude in a simple pole model and the parity violating piece in a simple quark picture.[15] Results of these calculations are shown in Table 5

To my knowledge, the only comprehensive calculation which has been undertaken to date is that of our group at UMass. In the case of the parity

	McK-Gib[12] $\pi + \rho$	McK-Gib[12] $\pi - \rho$	Nard.[15]
$\frac{1}{\Gamma_\Lambda} \Gamma_{NM}$	3.52	0.72	0.7

Table 5: Nonmesonic decay rates in nuclear matter in pi plus rho exchange models

violating interaction we employed a variant of the (broken) $SU(6)_w$ symmetry calculations which were employed successfully by Desplanques, Donoghue and Holstein to calculate the various weak NNM couplings in the case of nuclear parity violation.[8] In this approach there exist three (in principle unknown) reduced matrix elements which, when multiplied by the relevant generalized “Clebsch-Gordan” coefficients, relate all such parity-violating amplitudes. Two of these are determined empirically in terms of experimental hyperon decay data, while the third is given by a factorization calculation. While the success of this approach in the case of nuclear parity violation is not without question,[16] this procedure provides a plausible and unambiguous approach to the problem.

More difficult is the determination of the parity-conserving weak couplings. In this case we employ a pole model using the diagrams shown in Figure 3. What is needed here are the weak parity-conserving amplitudes for $\Lambda - N$ and $\Sigma - N$ transitions, which we determine via the current algebra (chiral symmetry) relations

$$\begin{aligned} \lim_{q_\pi \rightarrow 0} \langle \pi^0 n | \mathcal{H}_w^{(-)} | \Lambda \rangle &= \frac{-i}{F_\pi} \langle n | [F_{\pi^0}^5, \mathcal{H}_w^{(-)}] | \Lambda \rangle = \frac{i}{2F_\pi} \langle n | \mathcal{H}_w^{(=)} | \Lambda \rangle \\ \lim_{q_\pi \rightarrow 0} \langle \pi^0 p | \mathcal{H}_w^{(-)} | \Sigma^+ \rangle &= \frac{-i}{F_\pi} \langle p | [F_{\pi^0}^5, \mathcal{H}_w^{(-)}] | \Sigma^+ \rangle = \frac{i}{2F_\pi} \langle p | \mathcal{H}_w^{(-)} | \Sigma^+ \rangle \end{aligned} \quad (12)$$

and the weak $K - \pi$ coupling which is similarly given in terms of the experimental $K\pi\pi$ decay amplitude

$$A_{K\pi} = -iF_\pi \frac{k \cdot q}{m_K^2 - m_\pi^2} \langle \pi^0 \pi^0 | \mathcal{H}_w | K^0 \rangle_{\text{physical}} \quad (13)$$

Again this procedure has well documented flaws.[17] However, in the present context it is reasonable successful and for a first generation calculation, we

Figure 3: Pole diagrams used in evaluation of weak parity-conserving $\Lambda N \rightarrow NN$ couplings.

consider it to provide a reasonable estimate for the parity conserving weak couplings.

Combining with the various strong meson couplings we can now substitute into the diagrams shown in Figure 3 to generate the many effective parity conserving two-body operators which can be used to evaluate the nonmesonic decay amplitudes. Details of these procedures are given in ref. 10. Using the resultant two-body operators one can then generate the various predictions for nonmesonic decay in nuclear matter. Results are summarized in table 6, where we specifically identify the contributions from various channels.

The results are very intriguing. The overall decay rate is reduced somewhat from its pion-exchange-only value, in agreement with the experimental results. More striking is the modification of the p/n ratio and in the ratio of parity violating to parity conserving decay, defined as

$$\Gamma_{NM}(PV/PC) = \frac{\int_0^{\mu_{\Lambda N}} p^2 dp q (|b|^2 + |e|^2 + |f|^2)}{\int_0^{\mu_{\Lambda N}} p^2 dp q (|a|^2 + |c|^2 + 3|d|^2)} \quad (14)$$

values of which are shown in Table 7. We observe that inclusion of additional exchanges plays a major role in reducing the p/n ratio from its pion-only-

	π (no corr.)	π (corr.)	$\pi + \rho$	π, ρ, η ω, K, K^*
$^1S_0 \rightarrow ^1S_0$	.010	.000	.001	.001
$^1S_0 \rightarrow ^3P_0$	.156	.037	.052	.018
$^3S_1 \rightarrow ^3P_1$	.312	.117	.113	.456
$^3S_1 \rightarrow ^1P_1$	.468	.128	.100	.110
$^3S_1 \rightarrow ^3S_1$	.010	.789	.589	.202
$^3S_1 \rightarrow ^3D_1$	2.93	.751	.693	.444
Total	3.89	1.82	1.55	1.23

Table 6: Decay rates for various combinations of meson exchange in nuclear matter.

	$\Gamma_{NM}(PV/PC)$	$\Gamma_{NM}(p/n)$
π (no corr.)	0.14	11.2
π (with corr.)	0.18	16.6
$\pi + \rho$	0.21	13.1
$\pi, \rho, \omega, \eta, K, K^*$	0.90	2.9

Table 7: The parity violating to parity conserving and p to n ratios for hypernuclear decay in “nuclear matter.”

exchange value. The resulting value of 2.9 is still somewhat larger than the experimental values shown in Table 1 but clearly indicate the presence of non-pion exchange components.

The reason that kaon exchange in particular can play such a major role can be seen from a simple argument due to Gibson[18] who pointed out that since the final NN system can have either $I=0$ or $I=1$, the effective kaon exchange interaction can be written as

$$\begin{aligned}\mathcal{L}_{eff} &= A_0(\bar{p}p + \bar{n}n)\bar{n}\Lambda + A_1(2\bar{n}p\bar{p}\Lambda - (\bar{p}p - \bar{n}n)\bar{n}\Lambda) \\ &\sim (A_0 - 3A_1)\bar{p}p\bar{n}\Lambda + (A_0 + A_1)\bar{n}n\bar{n}\Lambda\end{aligned}\quad (15)$$

where the second line is obtained via a Fierz transformation. Since for parity violating kaon exchange we have $A_0 \sim 6A_1$ we find[18]

$$\Gamma_{NM}(p/n) = \left(\frac{A_0 - 3A_1}{A_0 + A_1}\right)^2 \sim 1/5 \quad (16)$$

which clearly indicates the importance of inclusion of non-pion-exchange components in predicting the p/n ratio.

A second strong indication of the presence of non-pion-exchange can be seen from Table 7 in that the rate of parity violating to parity conserving transitions is substantially enhanced by the inclusion of kaon and vector meson exchange as compared to the simple pion-exchange-only calculation. We can further quantify this effect by calculating explicitly the angular distribution of the emitted proton in the $\Lambda p \rightarrow np$ transition (there can be no asymmetry for the corresponding $\Lambda n \rightarrow nn$ case due to the identity of the final state neutrons), yielding

$$W_p(\theta) \sim 1 + \alpha P_\Lambda \cos \theta \quad (17)$$

where

$$\alpha = \frac{\int_0^{\mu_{\Lambda N} k_F} p^2 dp q \frac{\sqrt{3}}{2} \text{Re} f^*(\sqrt{2}c + d)}{\int_0^{\mu_{\Lambda N} k_F} p^2 dp q \frac{1}{4} (|a|^2 + |b|^2 + 3|c|^2 + 3|d|^2 + 3|e|^2 + 3|f|^2)} \quad (18)$$

is the asymmetry parameter. Results of a numerical evaluation are shown in Table 8 so that again inclusion of non-pion-exchange components has a significant effect, increasing the expected $\Lambda p \rightarrow np$ asymmetry by more than a factor of two. This prediction of a substantial asymmetry is consistent with preliminary results obtained for p-shell nuclei at KEK.[19]

	π -no corr.	π -corr.	all exch.
α	-0.078	-0.192	-0.443

Table 8: Proton asymmetry coefficient in various scenarios.

	Oset-Sal[13]	TRIUMF[20]	UMass[14]
$\frac{1}{\Gamma_\Lambda}\Gamma_{NM} \pi$ (no corr.)		1.6	3.4
π (corr.)	1.5	2.0	0.5
$\pi + K$ [20]; $\pi, \eta, \rho\omega, K, K^*$ [14]		1.2	0.2
$\Gamma_{NM}(p/n)\pi$ (no corr.)		5.0	4.6
π (corr.)		5.0	5.0
$\pi + K$ [20]; $\pi, \eta, \rho, \omega, K, K^*$ [14]		4.0	1.2
$\Gamma_{NM}(PV/PC)\pi$ (no corr.)		0.4	0.1
π (corr.)		0.5	0.1
$\pi + K$ [20]; $\pi, \eta, \rho, \omega, K, K^*$ [14]		0.3	0.8

Table 9: Calculated properties of nonmesonic hypernuclear decay of $^{12}_\Lambda\text{C}$.

3 – Hypernuclear Decay in Finite Nuclei

Although the nuclear matter calculations are of great interest in identifying basic properties of the decay process, true confrontation with experiment requires calculations involving the finite nuclei on which the measurements are conducted. Of course, such calculations are considerably more challenging than their nuclear matter counterparts and require Λ shell model considerations as well as non-S-wave capture. Nevertheless a number of groups have taken up the challenge. For the case of the nonmesonic decay of $^{12}_\Lambda\text{C}$ the results are summarized in Table 9. In comparing with the experimental results given in Table 1, we see that the UMass calculation is certainly satisfactory, but the discrepancy between the UMass and TRIUMF work is disturbing and needs to be rectified before either is to be believed.

A second nucleus on which there has been a good deal of work, both experimentally and theoretically, is $^5_\Lambda\text{He}$, which is summarized in Table 10.

	Oset-Sal[13]	TRIUMF[20]	TTB[21]	UMass[14]
$\frac{1}{\Gamma_\Lambda}\Gamma_{NM}\pi(\text{no corr.})$		1.0	0.5	1.6
$\pi(\text{corr.})$	1.15	0.25	0.144	0.9
$\pi + K[20]; \pi, \eta, \rho, \omega, K, K^*[14]$		0.22		0.5
$\Gamma_{NM}(p/n)\pi(\text{no corr.})$		5.0		15
$\pi(\text{corr.})$		4.8		19
$\pi + K[20]; \pi, \eta, \rho, \omega, K, K^*[14]$		5.4		2.1

Table 10: Calculated properties of the nonmesonic decay of ${}^5_\Lambda\text{He}$.

Here again what is important is not so much the agreement of disagreement with experiment but rather the discrepancies *between* the various calculations which need to be clarified before any significant confrontation between theory and experiment is possible.

Before leaving this section, it is important to raise an additional issue which needs to be resolved before reliable theoretical calculations are possible—that of the $\Delta I = \frac{1}{2}$ rule.[22] Certainly in any venue in which it has been tested—nonleptonic kaon decay— $K \rightarrow 2\pi, 3\pi$, hyperon decay— $B \rightarrow B'\pi$, $\Delta I = \frac{1}{2}$ components of the decay amplitude are found to be a factor of twenty or so larger than their $\Delta I = \frac{3}{2}$ counterparts. Thus it has been natural in theoretical analysis of nonmesonic hypernuclear decay to make this same assumption. (Indeed without it the already large number of unknown parameters in the weak vertices expands by a factor of two.) However, recently Schumacher has raised a serious question about the correctness of this assumption, which if verified will have serious implications about the direction of future theoretical analyses.[23] The point is that by use of very light hypernuclear systems one can isolate the isospin structure of the weak transition. Specifically, using a simple delta function interaction model of the hypernuclear weak decay process, as first written down by Block and Dalitz in 1963[24], one determines

$$\begin{aligned}
{}^4_\Lambda\text{He} : \gamma_4 &= \Gamma_{NM}(n/p) = \frac{2R_{n0}}{3R_{p1} + R_{p0}} \\
{}^5_\Lambda\text{He} : \gamma_5 &= \Gamma_{NM}(n/p) = \frac{3R_{n1} + R_{n0}}{3R_{p1} + R_{p0}}
\end{aligned}$$

$$\gamma = \Gamma_{NM}({}^4_{\Lambda}\text{He})/\Gamma_{NM}({}^4_{\Lambda}\text{H}) = \frac{3R_{p1} + R_{p0} + 2R_{n0}}{3R_{n1} + R_{n0} + 2R_{p0}} \quad (19)$$

where here R_{Nj} indicates the rate for N-stimulated hypernuclear decay from an initial configuration having spin j . One can then isolate the ratio R_{n0}/R_{p0} by taking the algebraic combination

$$\frac{R_{n0}}{R_{p0}} = \frac{\gamma\gamma_4}{1 + \gamma_4 - \gamma\gamma_5} \quad (20)$$

and from the experimental values[25]

$$\gamma_4 = 0.27 \pm 0.14, \quad \gamma_5 = 0.93 \pm 0.55, \quad \gamma = 0.73^{+0.71}_{-0.22} \quad (21)$$

we determine

$$\frac{R_{n0}}{R_{p0}} = \frac{0.20^{+0.22}_{-0.12}}{0.59^{+0.80}_{-0.47}} \quad (22)$$

in possible conflict with the $\Delta I = \frac{1}{2}$ rule prediction— $R_{n0}/R_{p0} = 2$.¹ If confirmed by further theoretical and experimental analysis this would obviously have important ramifications for hypernuclear predictions. However, recent work at KEK has indicated that the correct value for γ should be nearer to unity than to the value 0.73 used above in which case the ratio is considerably increased and there may be no longer any indication of $\Delta I = \frac{1}{2}$ rule violation.[26]

4 – Conclusions

We have given a brief overview of the field of weak hypernuclear physics. Because of limited experimental data and of the difficulty of doing reliable theory, the present situation is quite unsatisfactory. Although there is very rough qualitative agreement between theoretical expectations and experimental measurements, it is not clear whether discrepancies which do exist are due to experimental uncertainties, to theoretical insufficiencies, or both. On the theoretical side, what is needed are reliable calculations on finite hypernuclei (preferably by more than one group) which clearly indicate what

¹Note that final state nn or np configurations which arise from initial 1S_0 states are of necessity $I=1$.

signals should be sought in the data. The issue associated with the validity of the $\Delta I = \frac{1}{2}$ rule must be clarified. In addition there have been recent speculations about the importance of two-nucleon stimulated decay[27] (which could account for as much as 15% of the decay amplitude according to some estimates) and of the importance of direct quark (*i.e.* non-meson-exchange) mechanisms,[28] which deserve further study in order to eliminate the vexing double counting problems which arise when both direct quark and meson exchange components are included. On the experimental side, we require an extensive and reliable data base developed in a variety of nuclei in order to confirm or refute the predicted patterns. Clearly the strong program of hypernuclear physics at DAΦNE will provide a major step in this direction.

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